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Integrated Data Collection Analysis (IDCA) Program - RDX Standard Data Sets

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Integrated Data Collection Analysis (IDCA) Program —RDX Standard Data Sets

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ABSTRACT

The Integrated Data Collection Analysis (IDCA) program is conducting a proficiency study for Small-Scale Safety and Thermal (SSST) testing of homemade explosives (HMEs). Described here are the results for impact, friction, electrostatic discharge, and differential scanning calorimetry analysis of the RDX Type II Class 5 standard, for a third and fourth time in the Proficiency Test and averaged with the analysis results from the first and second time. The results, from averaging all four sets (1, 2, 3 and 4) of data suggest a material to have slightly more impact sensitivity, more BAM friction sensitivity, less ABL friction sensitivity, similar ESD sensitivity, and same DSC sensitivity, compared to the results from Set 1, which was used previously as the values for the RDX standard in IDCA Analysis Reports.

This effort, funded by the Department of Homeland Security (DHS), ultimately will put the issues of safe handling of these materials in perspective with standard military explosives. The study is adding SSST testing results for a broad suite of different HMEs to the literature. Ultimately the study has the potential to suggest new guidelines and methods and possibly establish the SSST testing accuracies needed to develop safe handling practices for HMEs. Each participating testing laboratory uses identical test materials and preparation methods wherever possible. Note, however, the test procedures differ among the laboratories. The results are compared among the laboratories and then evaluated based on testing method differences. The testing performers involved are Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Indian Head Division, Naval Surface Warfare Center, (NSWC IHD), Sandia National Laboratories (SNL), and Air Force Research Laboratory (AFRL/RXQL). These tests are conducted as a proficiency study in order to establish some consistency in test protocols, procedures, and experiments and to compare results when these testing variables cannot be made consistent.

Keywords: Small-scale safety testing, proficiency test, impact-, friction-, spark discharge-, thermal testing, round-robin test, safety testing protocols, HME, RDX, potassium perchlorate, potassium chlorate, sodium chlorate, sugar, dodecane, PETN, carbon.

IDCA Explosives Safety Testing for The Department of Homeland Security
Integrated Data Collection Analysis Program

1 INTRODUCTION

The IDCA Proficiency Test was designed to assist the explosives community in comparing and perhaps standardizing inter-laboratory Small-Scale Safety and Thermal (SSST) testing for improvised explosive materials (homemade explosives or HMEs) and aligning these procedures with comparable testing for typical military explosives[1]. The materials for the Proficiency Test have been selected because their properties invoke challenging experimental issues when dealing with HMEs. Many of these challenges are not normally encountered with military type explosives. To a large extent, the issues are centered on the physical forms and stability of the improvised materials.

Often, HMEs are formed by mixing oxidizer and fuel precursor materials, and typically, the mixture precursors are combined shortly before use. The challenges to produce a standardized inter-laboratory sample are primarily associated with mixing and sampling. For solid-solid mixtures, the challenges primarily revolve around adequately mixing two powders on a small scale, producing a mixture of uniform composition—particle size and dryness often being a factor—as well as taking a representative sample. For liquid-liquid mixtures, the challenges revolve around miscibility of the oxidizer with the fuel causing the possibility of multiphase liquid systems. For liquid-solid mixtures, the challenges revolve around the ability of the solid phase to mix completely with the liquid phase, as well as minimizing the formation of intractable or ill-defined slurry-type products.

Table 1. Materials for IDCA Proficiency study

Oxidizer/Explosive	Fuel	Description
Potassium perchlorate	Aluminum	Powder mixture
Potassium perchlorate	Charcoal	Powder mixture
Potassium perchlorate	Dodecane[1]	Wet powder
Potassium chlorate	Dodecane[1]	Wet powder
Potassium chlorate as received	Sucrose (icing sugar mixture)[2,3]	Powder mixture
Potassium chlorate -100 mesh[3]	Sucrose (icing sugar mixture)[2,3]	Powder mixture
Sodium chlorate	Sucrose (icing sugar mixture)[2,3]	Powder mixture
Ammonium nitrate		Powder
Bullseye® smokeless powder[4]		Powder
Ammonium nitrate	Bullseye® smokeless powder[4]	Powder mixture
Urea nitrate	Aluminum	Powder mixture
Urea nitrate	Aluminum, sulfur	Powder mixture
Hydrogen peroxide 70%	Cumin	Viscous paste
Hydrogen peroxide 90%	Nitromethane	Miscible liquid
Hydrogen peroxide 70%	Flour (chapatti)	Sticky paste
Hydrogen peroxide 70%	Glycerine	Miscible liquid
HMX Grade B		Powder
RDX Class 5 Type II		Powder (standard)
PETN Class 4		Powder (standard)

1. Simulates diesel fuel; 2. Contains 3 wt. % cornstarch; 3. Sieved to pass through 100 mesh; 4. Alliant Bullseye® smokeless pistol gunpowder.

The IDCA has chosen several formulations to test that present these challenges. Table 1 shows the materials selected for the Proficiency Test and the Description column describes the form of the resulting mixture.

Evaluation of the results of SSST testing of unknown materials, such as the HMEs in Table 1, is generally done as a relative process, where an understood standard is tested alongside the HME. In many cases, the standard employed is PETN or RDX. The standard is obtained in a high purity, narrow particle size range, and measured frequently. The performance of the standard is well documented on the same equipment (at the testing laboratory), and is used as the benchmark. The sensitivity to external stimuli and reactivity of the HME (or any energetic material) are then evaluated relative to the standard.

Most of the results from SSST testing of HMEs are not analyzed any further than this. The results are then considered in-house. This approach has worked very well for military explosives and has been a validated method for developing safe handling practices. However, there has never been a validation of this method for HMEs. Although it is generally recognized that these SSST practices are acceptable for HME testing, it must always be kept in mind that HMEs have different compositional qualities and reactivities than conventional military explosives.

The IDCA is attempting to evaluate SSST testing methods as applied to HMEs. In addition, the IDCA is attempting to understand, at least in part, the laboratory-to-laboratory variation that is expected when examining the HMEs. The IDCA team has taken several steps to make this inter-laboratory data comparison easier to analyze. Each participating laboratory uses materials from the same batches and follows the same procedures for synthesis, formulation, and preparation. In addition, although the Proficiency test allows for laboratory-to-laboratory testing differences, efforts have been made to align the SSST testing equipment configurations and procedures to be as similar as possible, without significantly compromising the standard conditions under which each laboratory routinely conducts their testing.

The first and basic step in the Proficiency test is to have representative data on a standard material to allow for performance comparisons. Table 1 includes some standard military materials. Class 5 Type II RDX was chosen as the primary standard, and Class 4 PETN was chosen as a secondary material. These materials are being tested in triplicate and RDX will continue to be tested throughout the IDCA Proficiency test.

In this report, the RDX standard has been examined for a third and fourth time. The Standard has been tested a minimum of one time and a maximum of four times throughout the Proficiency Test. LLNL, LANL, IHD, AFRL, and SNL all have examine the RDX previously[2]. Only LLNL, LANL and IHD tested the standard a third and fourth time and these results are presented here. In addition, the previous RDX results are compared and average values of RDX are derived. And compared on an inter- and intra-laboratory basis.

The testing performers in this work are Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), and Indian Head Division, Naval Surface Warfare Center, (NSWC IHD).

2 EXPERIMENTAL

General information. All samples were prepared according to IDCA methods on drying and mixing procedures[3,4]. Briefly, the sample was dried in an oven at 60°C for 16 h, then cooled and stored in a desiccator until use. The RDX used in this effort is Class 5 Type II RDX and was obtained from the Holston Army Ammunition Plant batch # HOL89D675-081 and provided to the participating laboratories test by IHD[5]. High Performance Liquid Chromatography analysis gave 90% RDX and 10% HMX; Laser Diffraction (Light Scattering method using Microtracs Model FRA9200) gave a particle size distribution of 7.8 to 104.7 micron with a maximum at 31.1 microns[6,7].

Table 2. Summary of conditions for the analysis of RDX (All = LANL, LLNL, IHD)

Impact Testing

1. Sample size—LLNL, IHD, 35 ± 2 mg; LANL 40 ± 2 mg
2. Preparation of samples—All, dried per IDCA drying methods[3]
3. Sample form—All, loose powder; LLNL, pressed
4. Powder sample configuration—All, conical pile; LLNL pellet also
5. Apparatus—All, Type 12*
6. Sandpaper—All (180-grit garnet); LANL (150-grit garnet); LLNL (120-grit Si/Carbide)
7. Sandpaper size—LLNL, IHD, 1 inch square; LANL, 1.25 inch diameter disk dimpled
8. Drop hammer weight—All, 2.5 kg
9. Striker weight—LLNL, IHD, 2.5 kg; LANL 0.8 kg
10. Positive detection—LANL, LLNL, microphones with electronic interpretation as well as observation; IHD, observation
11. Data analysis—All, modified Bruceton and TIL before and above threshold; LANL Neyer also

Friction analysis

1. Sample size—All, ~5 mg, but not weighed
2. Preparation of samples—All, dried per IDCA procedures[3]
3. Sample form—All, powder
4. Sample configuration—All, small circle form
5. Apparatus—LANL, LLNL, IHD, BAM; IHD, ABL
6. Positive detection—All, by observation
7. Room Lights—LANL on, LLNL off; IHD, BAM on, ABL off
8. Data analysis—LLNL modified Bruceton (log-scale spacing) and TIL; LANL, modified Bruceton (linear spacing) and TIL; IHD Neyer and TIL

ESD

1. Sample size—All ~5 mg, but not weighed
2. Preparation of samples—All, dried per IDCA drying methods[3]
3. Sample form—All, powder
4. Tape cover—LANL, scotch tape; LLNL, Mylar; IHD none
5. Sample configuration—All, cover the bottom of sample holder
6. Apparatus—All, ABL; LLNL, custom built*
7. Positive detection—All observation
8. Data analysis methods—All, TIL

Differential Scanning Calorimetry

1. Sample size—All, ~ <1 mg
2. Preparation of samples—LLNL, LANL and IHD, dried per IDCA procedures[3]
3. Sample holder—All, pinhole; LLNL and IHD, hermetically sealed
4. Scan rate—All, 10°C/min
5. Range—All 40 to 400°C
6. Sample holder hole size—LANL, IHD, 75 μm; LLNL 50 μm
7. Instruments—LANL, TA Instruments Q2000; LLNL, TA Instruments 2920; IHD, TA Instruments Q1000*

Footnotes: *Test apparatus, *Impact:* LANL, LLNL, IHD—ERL Type 12 Drop Weight Sensitivity Apparatus, AFRL, SNL— MBOM modified for ERL Type 12 Drop Weight; *Friction*: LANL, LLNL, IHD, SNL—BAM Friction Apparatus, LANL, IHD, AFRL—ABL Friction Apparatus; *Spark:* LLNL, LANL, IHD, AFRL, SNL—ABL Electrostatic Discharge Apparatus, LLNL—custom-built Electrostatic Discharge Apparatus; *Differential Scanning Calorimetry:* LANL—TA Instruments Q1000, Q2000, LLNL—TA Instruments 2910, 2920, Setaram Sensys DSC, IHD—TA Instruments Model 910, 2910, Q1000, AFRL—TA Instruments Q2000.

Testing conditions. Table 2 summarizes the SSST testing conditions used by the laboratories that participated in the analyses of the RDX Type II Class 5. The SSST testing data for the individual participants was obtained from the following IDCA Data reports: Small Scale Safety Test Report for RDX (third in a series) (LLNL)[8], Small Scale Safety Test Report for RDX (4th in a series) revised for 1-kg striker data (LLNL)[9], 50188 I RDX Third time (LANL)[10], 50188 V RDX 4th Time (LANL)[11], and RDX Report Run #3 (IHD)[12].

3 RESULTS

3.1 RDX Type II Class 5

In this proficiency test, all testing participants are required to use materials from the same batch, and mixtures are to be prepared by the same methods. However, the actual testing procedures can be different. These differences are described in the IDCA report on method comparisons[13], which compares the different procedures by each testing category. LANL, LLNL, and IHD participated in this part of the SSST testing of the RDX.

RDX in this study is Type II was provided and distributed by IHD from inventory. RDX Type II is from the acetic anhydride (Bachman) process and generally contains ~ 10-wt % HMX as a by-product[14]. The HMX content has been verified by HPLC analysis[6]. The Military Specification for RDX Type II Class 5 is that a minimum of 97-wt % of the materials passes through a 325-mesh (44 μm[15]) sieve fraction[16]. More details on the characterization of this material are in the RDX Set 1[2] and Set 2 reports[17].

Listed below are data from LLNL Set 1-4, LANL Set 1-4, and IHD Set 1-3. The tables will reflect averages of the data sets. The full data sets are given in the Appendices. Set 1 data from AFRL and Set 2 data from SNL is not included in the tables, but will be compared in the Discussion section. The selection of what data to average depends upon what testing variables are of interest for analysis. For DH_{50} Bruceton and DH_{50} Neyer values, the average and standard deviation were calculated using an Excel spreadsheet. In most cases, averages were calculated with data sets of 3 points or larger. In a few cases, the data sets were limited to 2 data points. In these cases, the average and deviation were calculated because it was the only data available from the specific source. Also, in rare cases, only one data point was available. Those types of results have no ± value. All exceptions are footnoted in the tables. For the TIL values (friction and ESD), the value reported is the arithmetic average of the TIL values. This can result in a TIL level that really was not measured. This method is used, for lack of any other quick method for analysis. For the level above TIL, TIL+, the level that positive reaction is noted, the arithmetic average was calculated, as well, the number of positives reactions (X/10, for example) was averaged also. Again, this also can result in a level that really was not measured. In the case of the DSC data, T_{min}, T_{max}, and ΔH values, the average and standard deviation were calculated using an Excel spreadsheet, usually of 3 or more data points, yielding an average of a data set. When overall average values were calculated, average was taken of all the individual data points, not of the averages of the average of each data set. As a result of these inexact methods, the reported average values are meant to be guiding values only. A full statistical examination of these results will be presented elsewhere.

3.2 Impact testing results for RDX Type II Class 5

Table 3 shows the average results of impact testing of the RDX Type II Class 5 as performed by LANL, LLNL, and IHD for all data sets available taken during the Proficiency test. A full listing of the individual testing results are found in Appendix 1, below. Differences in the testing procedures are shown in Table 2, and the notable differences are variation in sandpaper type, amount of sample, and the methods for detection of a positive test. All participants performed data analysis by normal modified Bruceton method[18,19]. The table shows the average values grouped based on specific parameters. The parameters chosen are sandpaper type, drop weight, and RDX set (first through fourth time examined).

LLNL measured impact data using 120-grit Si/C and 180-grit garnet sandpapers. The 120-grit sandpaper is the standard configuration used by LLNL when testing outside of the Proficiency Test. The DH_{50} range for the 120-grit sandpaper, 2.5 kg striker weight tests (3 data points), excluding pressed, which will be discussed below, is 23.9 to 24.7 cm, and for the 180-grit sandpaper, 2.5 kg striker weight tests (7 data points) is 21.3 to 23.9 cm, showing a minimal overlap, statistically. LLNL also varied the striker weight when using 180-grit sandpaper. The DH_{50} range for the 180-grit sandpaper, 1.0 kg striker weight tests (2 data points) is 25.9 to 26.7 cm, which is outside the range of the 180-grit sandpaper, 2.5 kg striker weight test range shown above. LLNL also measured impact data on pressed RDX. The DH_{50} range for the 120-grit sandpaper, 2.5 kg striker weight tests (2 data points) is 27.7 to 35.1 cm which is outside the range of the 120-grit sandpaper, 2.5 kg striker data above and outside DH_{50} range for all LLNL data except pressed (19 data points) which is 21.5 to 24.9 cm.

LANL measured impact data using 150-grit garnet and 180-grit garnet sandpapers. The 150-grit sandpaper is the standard configuration used by LANL when testing outside the Proficiency Test. LANL also uses a 0.8 kg striker weight. The DH_{50} range for the 150-grit garnet sandpaper, 0.8 kg striker weight tests (3 data points) is 24.2 to 26.6 cm and the DH_{50} range for the 180-grit garnet sandpaper, 0.8 kg striker weight tests (9 data points) is 18.9 to 22.9 cm. There is no overlap of these values.

IHD measured impact data using 180-grit garnet sandpaper only, which is their standard configuration when testing outside the Proficiency Test. The DH_{50} range for the 180-grit garnet sandpaper, 2.5 kg striker weight is 16.9 to 22.5 cm. Comparing this range to the DH_{50} ranges for LLNL and LANL for 180-grit garnet sandpaper shown above indicates there is some overlap among all three participants, although the average values follow this trend LLNL > LANL > IHD.

Table 3. Average Impact testing results for RDX Type II Class 5

Lab	Sample Description[1]	DH_{50}, cm[2,3]
LLNL	120-grit sandpaper, 2.5 kg striker weight, Set 1[4]	24.1 ± 0.1
LLNL	180-grit sandpaper, 2.5 kg striker weight, Set 2[4]	21.8 ± 1.6
LLNL	120-grit sandpaper, 2.5 kg striker weight, Set 3[5]	24.8
LLNL	180-grit sandpaper, 2.5 kg striker weight, Set 3[4]	22.1 ± 1.0
LLNL	180-grit sandpaper, 2.5 kg striker weight, Set 4	23.4 ± 1.4
LLNL	180-grit sandpaper, 1.0 kg striker weight, Set 4	26.3 ± 0.4
LLNL	120-grit sandpaper, 2.5 kg striker weight, Set 1 & 2 pressed[4,6]	31.4 ± 3.7
LANL	150-grit sandpaper, 0.8 kg striker weight, Set 1	25.4 ± 1.2
LANL	180-grit sandpaper, 0.8 kg striker weight, Set 2	20.8 ± 1.1
LANL	180-grit sandpaper, 0.8 kg striker weight, Set 3	23.2 ± 0.1
LANL	180-grit sandpaper, 0.8 kg striker weight, Set 4	18.8 ± 1.0
IHD	180-grit sandpaper, 2.5 kg striker weight, Set 1	19.3 ± 1.9
IHD	180-grit sandpaper, 2.5 kg striker weight, Set 2	17.7 ± 3.1
IHD	180-grit sandpaper, 2.5 kg striker weight, Set 3	22.3 ± 1.5
LLNL	120-grit sandpaper, 2.5 kg striker weight, all, except pressed[6]	24.3 ± 0.4
LLNL	180-grit sandpaper, 2.5 kg striker weight, all, except pressed[6]	22.6 ± 1.3
LLNL	180-grit sandpaper, all, except pressed[6]	23.4 ± 2.0
LLNL	Average except pressed[6]	23.2 ± 1.7
LANL	180-grit sandpaper, 0.8 kg striker weight, all	20.9 ± 2.0
LANL	Average	22.4 ± 2.7
IHD	Average	19.7 ± 2.8

1. Sample description: 180-grit sandpaper is 180 garnet dry, 150-grit sandpaper is garnet dry, 120-grit sandpaper is 120 Si/Carbide wet/dry, Set 1-4 is data from RDX testing Set 1-4, respectively; 2. DH_{50}, in cm, by modified Bruceton method, height for 50% probability of reaction; 3. average of several data sets, unless indicated; 4. 2 data points only; 5. 1 data point only; 6. pressed into pellet.

LANL also measured impact sensitivity of the RDX using the 150-grit and 180-grit garnet sandpaper using the Neyer or D-Optimal data reduction method[20]. Table 4 shows the impact test results. The DH_{50} range for 150-grit garnet sandpaper, 0.8 kg striker weight is 23.3 to 26.1 cm. The DH_{50} range or 180-grit garnet sandpaper, 0.8 kg striker weight is 19.7 to 22.5 cm. Although these values are similar to the data above using the Bruceton method for analysis, the 150-grit and 180-grit DH_{50} ranges do not overlap.

Table 4. Impact testing results for RDX Type II Class 5 (Neyer or D-Optimal Method)

Lab	Sample Description[1]	DH_{50}, cm[2,3]
LANL	150-grit sandpaper, 0.8 kg striker weight, Set 1	24.7 ± 1.4
LANL	180-grit sandpaper, 0.8 kg striker weight, Set 2	21.2 ± 1.4
LANL	180-grit sandpaper, 0.8 kg striker weight, Set 3	21.7 ± 1.4
LANL	180-grit sandpaper, 0.8 kg striker weight, Set 4	20.2 ± 1.6
LANL	180-grit sandpaper, 0.8 kg striker weight, all	21.1 ± 1.4
LANL	Average[4]	22.1 ± 2.2

1. Sample description: 180-grit sandpaper is 180 garnet dry, 150-grit sandpaper is garnet dry, Set 1-4 is data from RDX testing Set 1-4, respectively; 2. DH_{50}, in cm, by Neyer method, height for 50% probability of reaction; 3. Average of several data sets, unless indicated; 4. Average of data taken with 180-grit sandpaper only.

3.3 Friction testing results for RDX Type II Class 5

Table 5 shows the average BAM Friction testing performed by LANL, LLNL, and IHD. The difference in testing procedures by the three laboratories is shown in Table 2, and the notable differences are in the methods for positive detection. A full listing of the data is shown in Appendix 2. LANL and LLNL performed data analysis using the threshold initiation level method (TIL)[21]. All participants also used a modified Bruceton method[18,19] and IHD used the Neyer method[20] on Data set 2 because their data did not meet Bruceton criteria (analysis performed by LANL). For the average overall TIL values, LLNL measures the RDX to be more stable than LANL and IHD. The F_{50} range for LLNL is 21.0 to 25.8 kg, for LANL is 15.6 to 21.0 kg, and for IHD is 18.7 to 19.9 kg. The LLNL and LANL values just overlap, but the LLNL average is much higher than the other laboratories for both TIL, TIL+ and F_{50}.

Table 5. Average BAM Friction Testing results for RDX Type II Class 5

Lab	Set	TIL, kg[1]	TIL+, kg[2]	F_{50}, kg[3,4]
LLNL	1	0/10 @ 19.2	1/10 @ 21.6	25.4 ± 0.8
LLNL	2	0/10 @ 16.5	1/10 @ 18.0	24.8 ± 1.5
LLNL	3	NA[5]	NA[5]	21.1 ± 1.8
LLNL	4	0/10 @ 16.3	1/10 @ 17.0	22.2 ± 2.4
LLNL	All	0/10 @ 17.3	1/10 @ 18.9	23.4 ± 2.4
LANL	1	0/10 @ 19.2	1/4 @ 21.6	20.8 ± 2.2
LANL	2	NA[5]	NA[5]	16.3 ± 1.1
LANL	3	0/10 @ 11.4	1/5 @ 13.9	15.6 ± 1.0
LANL	4	0/10 @ 13.9	1/7 @ 16.3	20.4 ± 1.0
LANL	All	0/10 @ 14.8	1/5 @ 17.3	18.3 ± 2.7
IHD	1	0/10 @ 15.1	1/4 @ 16.8	NA[6]
IHD[7,8]	2	NA[5]	NA[5]	27.8 ± 3.4
IHD	3	NA[5]	NA[5]	19.3 ± 0.6

1. Threshold Initiation Level (TIL) is the load (kg) at which zero reaction out of twenty or fewer trials with at least one reaction out of twenty or fewer trials at the next higher load level; 2. Next level where positive initiation is detected; 3. F_{50}, in kg, is by a modified Bruceton method, weight for 50% probability of reaction; 4. LLNL uses log-spacing and LANL uses liner spacing for the Bruceton up and down method experimentation and data analysis; 5. Not applicable, TIL analysis not performed; 6. Bruceton analysis not performed; 7. Neyer analysis performed by LANL; 8. F_{50}, in kg, is by Neyer method, weight for 50% probability of reaction.

Table 6 shows the average ABL Friction testing performed by IHD on RDX Type II Class 5. A full listing of the data is found in Appendix 2. LANL did not have the system in routine performance at the time and LLNL does not have ABL Friction. IHD performed data analysis using the threshold initiation level method (TIL)[21] and a modified Bruceton method[18,19]. The average of all F_{50} values range from 148 to 210 psig at 8 fps, and the TIL values are consistent throughout the data sets.

Table 6. Average ABL Friction testing results for RDX Type II Class 5

Lab	Set	TIL, psig/fps[1,2]	TIL+, psig/fps[1,3]	F_{50}, psig/fps[1,4]
IHD	1	0/20 @ 55/8	1/4 @ 74/8	141/8 ± 32/8
IHD	2	0/20 @ 92/8	1/5 @ 123/8	207/8 ± 15/8
IHD	3	0/20 @ 92/8	1/5 @ 123/8	178/8 ± 4/8
IHD	All	0/20 @ 80/8	1/5 @ 107/8	179/8 ± 31/8

1. psig/fps = pressure in psig at test velocity in feet per sec; 2. Threshold Initiation Level (TIL) is the load (psig) at test velocity (fps) at which zero reaction out of twenty or fewer trials with at least one reaction out of twenty or fewer trials at the next higher load level; 3. Next level where positive initiation is detected; 4. F_{50}, in psig/fps, is by a modified Bruceton method, force for 50% probability of reaction.

3.4 Electrostatic discharge testing of RDX Type II Class 5

Electrostatic Discharge (ESD) testing of the RDX Type II Class 5 was performed by LLNL, LANL, and IHD. Table 7 shows the average results from each data set. A full listing of the data is shown in Appendix 3. Differences in the testing procedures are shown in Table 2, and the notable differences are the use of tape and what covers the sample. All participants performed data analysis using the threshold initiation level method (TIL)[21].

LLNL used a custom built ESD system with a 510-Ω resistor in line to simulate a human body for Set 1 and Set 2. The average results in both cases were no sensitivity. LLNL also used a new ABL system for Set 3 and Set 4 and the average TIL is 0/10 at 0.038 J. This compares to the average TIL measured by LANL (also with an ABL system) of 0/20 at 0.027 J and IHD (also with an older ABL system) of 0/20 at 0.066 J.

Table 7. Average Electrostatic discharge testing results for RDX Type II Class 5

Lab	ESD, Ω	Set	TIL, J[1]	TIL+, J[2]
LLNL	Custom[3], 510	1	0/10 @ 1.0	0/10 @ 1.0
LLNL	Custom[3], 510	2	0/10 @ 1.0	0/10 @ 1.0
LLNL	ABL, 0	3	0/10 @ 0.038	1/3 @ 0.063
LLNL	ABL, 0	4	0/10 @ 0.038	1/4 @ 0.063
LLNL	Custom[3], 510	All	0/10 @ 1.0	0/10 @ 1.0
LLNL	ABL, 0	All	0/10 @ 0.038	1/4 @ 0.063
LANL	ABL, 0	1	0/20 @ 0.025	1/8 @ 0.0625
LANL	ABL, 0	2	0/20 @ 0.0325	1/10 @ 0.0833
LANL	ABL, 0	3	0/20 @ 0.025	1/9 @ 0.0625
LANL	ABL, 0	4	0/20 @ 0.025	1/9 @ 0.0625
LANL	ABL, 0	All	0/20 @ 0.027	1/9 @ 0.068
IHD	ABL, 0	1	0/20 @ 0.095	1/10 @ 0.165
IHD	ABL, 0	2	0/20 @ 0.037	1/8 @ 0.095
IHD	ABL, 0	3	0/20 @ 0.067	1/8 @ 0.142
IHD	ABL, 0	All	0/20 @ 0.066	1/9 @ 0.134

1. Threshold Initiation Level (TIL) is the load (joules) at which zero reaction out of twenty or fewer trials with at least one reaction out of twenty or fewer trials at the next higher load level; 2. Next level where positive initiation is detected; 3. LLNL used a custom built ESD with a 510-Ω resistor in the discharge unit to mimic the human body

3.5 Thermal testing (DSC) of RDX Type II Class 5

Differential Scanning Calorimetry (DSC) was performed on the RDX Type II Class 5 by LLNL, LANL, and IHD. All participating laboratories used different versions of the DSC by TA Instruments. Results were obtained at a 10°C/min heating rate.

Table 8 shows the average values of the DSC from RDX Sets 1 through 4. A full listing of the data can be found in Appendix 4. The principal features of the DSC examinations are essentially the same from all participants—two overlapping low temperature endothermic features near 200°C and with enthalpy around 150 J/g and a major exothermic feature near 240°C with enthalpy around 2000 J/g. LLNL examined the RDX using an open sample holder and a sealed sample holder. The average values were calculated for both sets and are nearly identical. The enthalpy data of the exothermic feature from the sealed sample holder appears slightly higher than for the open system. LLNL and IHD found similar average results for all features, except for IHD Set 3, where the system seemed to vent in the high temperature range. As a result, IHD used a sealed sample holder for an extra round of testing for Set 3. The positions of the features were at slightly lower temperatures, and the enthalpy for the high temperature exothermic feature was around twice that of other measurements.

Table 8. Differential Scanning Calorimetry results for RDX Type II Class 5, 10°C/min heating rate

Participant[1,2]	T_{min} of En_1[3], °C	T_{min} of En_2[4], °C	ΔH of En_{1+2}[5], J/g	T_{max} of Ex_1[6], °C	ΔH of Ex_1[7], J/g
LLNL Set 1	189.1 ± 0.1 (0.1)	199.1 ± 0.3 (0.1)	139 ± 3 (2)	241.3 ± 0.6 (0.2)	2298 ± 18 (1)
LLNL Set 1H	189.0 ± 0.1 (0.1)	198.9 ± 0.2 (0.1)	131 ± 11 (8)	234.3 ± 1.2 (0.5)	2967 ± 77 (3)
LLNL Set 2	188.4 ± 0.2 (0.3)	199 ± 1 (0)[8]	130 ± 5 (4)	239.8 ± 1.0 (0.4)	2417 ± 17 (0)
LLNL Set 2H	188.3 ± 0.0 (0.0)	199 ± 0 (0)[8]	124 ± 9 (7)	233.3 ± 4.1 (1.8)	3600 ± 179 (5)
LLNL Set 3	189.1 ± 0.2 (0.1)	199.3 ± 0.2 (0.1)	158 ± 21 (13)	242.6 ± 0.8 (0.3)	2057 ± 257 (13)
LLNL Set 3H	189.1 ± 0.0 (0.0)[9]	199.3 ± 0.1 (0.1)[9]	138 ± 1 (1)[9]	240.1 ± 4.7 (2.0)[9]	2586 ± 82 (32)[9]
LLNL Set 4	188.9 ± 0.1 (0.0)	199.0 ± 0.3 (0.1)[10]	139 ± 4 (3)	234.6 ± 3.1 (1.3)	3104 ± 43 (14)
LLNL Set 4H	189.0 ± 0.0 (0.0)	199.2 ± 0.0 (0.0)	139 ± 8 (6)	242.8 ± 0.6 (0.2)	2203 ± 22 (1)
LLNL All	188.9 ± 0.3 (0.2)	199.2 ± 0.3 (0.2)	142 ± 14 (10)	239.5 ± 3.5 (1.5)	2469 ± 458 (19)
LLNL All H	188.8 ± 0.3 (0.2)	199.1 ± 0.2 (0.1)	133 ± 10 (8)	237.5 ± 5.0 (2.1)	2862 ± 263 (10)
LANL Set 1	189.3 ± 0.2 (0.1)	200.1 ± 0.5 (0.3	136 ± 1 (1)	242.1 ± 0.6 (0.2)	2237 ± 29 (1)
LANL Set 2	189.5 ± 0.3 (0.1)	200.2 ± 0.8 (0.4)	133 ± 6 (4)	242.5 ± 0.5 (0.2)	2176 ± 110 (5)
LANL Set 3	192.8 ± 5.2 (2.7)	200.3 ± 0.3 (0.1)	134 ± 4 (3)	242.2 ± 0.9 (0.4)	2131 ± 29 (1)
LANL Set 4	189.6 ± 0.1 (0.1)	200.2 ± 0.4 (0.2)	124 ± 11 (9)	243.2 ± 1.0 (0.4)	2056 ± 133 (6)
LANL All	190.3 ± 2.7 (1.4)	200.2 ± 0.5 (0.2)	132 ± 7 (5)	242.6 ± 0.8 (0.3)	2150 ± 102 (5)
IHD Set 1	189.0 ± 0.1 (0.1)	198.9 ± 0.2 (0.1)	131 ± 11 (8)	242.2 ± 0.3 (0.1)	2041 ± 97 (5)
IHD Set 2	189.4 ± 0.2 (0.1)	199.6 ± 0.4 (0.0)	102 ± 8 (8)	241.2 ± 1.4 (0.6)	1207 ± 238 (20)
IHD Set 3	189.2 ± 0.5 (0.3)	199.2 ± 0.6 (0.3)	120 ± 25 (21)	241.0 ± 1.0 (0.4)	2946 ± 1179 (40)
IHD Set 3H	188.6 ± 0.3 (0.2)	198.4 ± 0.3 (0.2)	98 ± 6 (6)	238.4 ± 1.3 (0.5)	4363 ± 95 (2)
IHD Set 4	189.6 ± 0.1	199.9 ± 0.2	142 ± 5	242.3 ± 0.6	2312 ± 74
IHD Set 4H	190	199.7 ± 0.1	100 ± 16	241.2 ± 0.7	4483 ± 245
IHD All	189.2 ± 0.3 (0.2)	199.4 ± 0.4 (0.2)	116 ± 17 (15)	241.8 ± 1.4 (0.6)	2172 ± 969 (45)

1. Set 1, Set 2 are from data using pinhole sample holder from reference 2 and 17, respectively; 2. Set 1H, Set 2H are from data using hermetically sealed sample holder from reference 2 and 17, respectively; 3. En_1 is the first endothermic feature as seen in Table 8; 4. En_2 is the second endothermic feature as seen in Table 8; 5. ΔH for endothermic features 1+2 as seen in Table 8; 6. Ex_1 is the exothermic feature as seen in Table 8; 7. ΔH for exothermic feature seen in Table 8; 8. Visually estimated from hard copy printout; 9. One data point not included due to visual approximation; 10. Averages of two data points only.

4 DISCUSSION

Table 9 shows the average values for all RDX Type II Class 5 data sets (Average of Sets) from each participant and compares it to corresponding data for the standard, RDX Type II Class 5 done previously (Set 1) and PETN. The Set 1 data for RDX comes from the IDCA first iterative study of RDX as part of this Proficiency Test[2], and the data for PETN comes from the examination of PETN Class 4 as part of this Proficiency Test[22]. The data chosen to be included in the average of all data sets, Average of Sets, was grouped with as many common parameters available. For examples, impact data for only the 180-grit sandpaper were included in the overall comparison, while the Set 1 data was taken with different sandpapers; most of the ESD data were taken on ABL ESD equipment except for some LLNL data taken on a custom built system. The comparison data in the Table 9 is useful because most of the Analysis reports released prior to this one used the average values from Data Set 1 for comparison.

Table 9. Average Comparison values

	LLNL	LANL	IHD
Impact Testing[1]	DH_{50}, cm	DH_{50}, cm	DH_{50}, cm
RDX Type II Class 5 Average of Sets[2,3]	22.6[4,5]	20.9[4,6]	19.7[4,7]
RDX Type II Class 5 Set 1[8]	24.1[9]	25.4[10]	19[4]
PETN[11]	10.9[6]	8.0[4]	9.3[4]
BAM Friction Testing[12,13]	TIL, kg; F_{50}, kg	TIL, kg; F_{50}, kg	TIL, kg; F_{50}, kg
RDX Type II Class 5 Average of Sets[2,14,15]	16.3; 23.4	14.8; 18.3	15.1[16]; 19.3[17]
RDX Type II Class 5 Set 1[8]	19.2; 25.1	19.2; 20.8	15.1; ND[18]
PETN[11]	6.4; 10.5	4.9, 8.5	4.3, 6.9
ABL Friction Testing[19-22]	TIL, psig; F_{50}, psig	TIL, psig; F_{50}, psig	TIL, psig; F_{50}, psig
RDX Type II Class 5 Average of Sets[2,23,24]	ND[18]; ND[18]	ND[18]; ND[18]	80; 179
RDX Type II Class 5 Set 1[8]	ND[18]; ND[18]	ND[18]; ND[18]	74; 154
PETN[11]	ND[18]; ND[18]	ND[18]; ND[18]	7.7, 42
Electrostatic Discharge[25]	TIL, Joules	TIL, Joules	TIL, Joules
RDX Type II Class 5 Average of Sets[2,26,27]	0/10 @ 0.038[28]	0/20 @ 0.027[28]	0/20 @ 0.066[28]
RDX Type II Class 5 Set 1[8]	0/10 @ 1.0[29]	0/20 @ 0.0250[28]	0/20 @ 0.095[28]
PETN[11]	0/10 @ 0.033[28]	0/20 @ 0.025[28]	0/20 @ 0.219[28]

1. DH_{50}, in cm, is by a modified Bruceton method, height for 50% probability of reaction; 2. The values selected for the Average of the Sets (Average of Sets) varying depending upon laboratory, for example, for impact, the sandpaper is 180—grit garnet, for ESD, ABL ESD apparatus or LLNL custom built; 3. Temperature and humidity values varied during the sets of measurements; 4. 180-grit sandpaper; 5. Average from Table 3 of Set 2, 3 and 4 with 2.5 kg striker, not pressed; 6. Average from Table 3 of Set 2, 3, and 4, 0.8 kg striker; 7. Average from Table 3 of Set 1, 2 and 3, 2.5 striker; 8. From reference 2; 9. 120-grit Si/C sandpaper data only; 10. 150-grit garnet sandpaper data only; 11. From reference 22; 12. Threshold Initiation Level (TIL) is the weight (kg) at which zero reaction out of twenty or fewer trials with at least one reaction out of twenty or fewer trials at the next higher load level; 13. F_{50}, in kg, is by a modified Bruceton method, weight for 50% probability of reaction; 14. Temperature and humidity values varied during the sets of measurements; 15. Average of measurements from Table 5; 16. TIL analysis only averaged for Set 1; 17. Bruceton analysis averaged only for Set 3; 18. ND = Not determined; 19. LLNL and LANL did not perform measurements; 20. Threshold Initiation Level (TIL) is the load (psig) at test velocity (fps) at which zero reaction out of twenty or fewer trials with at least one reaction out of twenty or fewer trials at the next higher load level; 21. F_{50}, in psig/fps, is by a modified Bruceton method, load for 50% probability of reaction; 22. Measurements performed at 8 fps; 23. Temperature and humidity values varied during the sets of measurements; 24. Average of measurements from Table 6; 25. Threshold Initiation Level (TIL) is the energy (joules) at which zero reaction out of twenty or fewer trials with at least one reaction out of twenty or fewer trials at the next higher load level; 26. Temperature and humidity values varied during the sets of measurements; 27. Average of measurements from Table 7; 28. ABL ESD apparatus; 29. LLNL has 510-Ω resistor in circuit.

4.1 Comparison of participating laboratory testing of RDX Type II Class 5

Impact sensitivity. The source of the data for calculating the average values for selected the Average of Sets shown in Table 9 are from experiments using 180-grit garnet sandpaper. 120-grit sandpaper data produced by LLNL and 150-grit sandpaper data produced by LANL were not included in the Average of Sets (see Table 3 and Appendix 1 for more details of the data selected for averaging). LLNL and LANL have similar results, with both using microphone systems for positive detection. The average value obtained from IHD data indicates a more sensitive material. IHD also uses observation only for positive detection.

Friction sensitivity. For BAM Friction, the Average of Sets TIL value for LLNL indicates a more stable material than the other participants, consistent with what has been found previously. This is thought to be due to extra safety shielding of the LLNL BAM system[23]. The F_{50} values exhibit the same trend—LLNL results show a more stable material. IHD was the only participant to do the ABL friction testing, so there is no comparison to be made.

ESD. The data for Average of Sets reported in Table 9 for were taken on ABL ESD systems. LLNL recorded data on both the ABL ESD system and a custom built system for Set 1 and Set 2 (see Table 7 and Appendix 3 for more details on selection of data). The data from the custom built system were not included in the Average of Sets. The variation of the Average of Sets values in Table 9 is probably related to the vintage of the ABL ESD equipment. This difference is reflected through the ability to select stimulation levels and how well the system has been kept calibrated. Order of sensitivity found: LANL > LLNL > IHD. The ABL ESD at IHD is the oldest equipment of the three laboratories and it is speculated that the age is responsible for some sensitivity differences.

Thermal sensitivity. All participants found the RDX Type II Class 5 material to have essentially the same behavior—two weak low temperature exothermic features just below 200°C and one prominent exothermic feature with a T_{max} near 240 °C. The choice of the type of sample holder, pinhole vented or sealed, made little difference in the data. When LLNL used a hermetically sealed sample holder the endothermic features of the DSC profiles exhibited a shift of ~ 0.1 °C lower in temperature and ~ 10 J/g lower in enthalpy, and the exothermic feature exhibiting a shift of 2 °C lower in temperature and a 400 J/g shift higher in enthalpy. The values in Table 8 are within the standard deviation of the measurements and are essentially the same, although evidence on other materials suggests that the sealed system is better for enthalpy assessments because of less loss to vaporization of volatile gases[2].

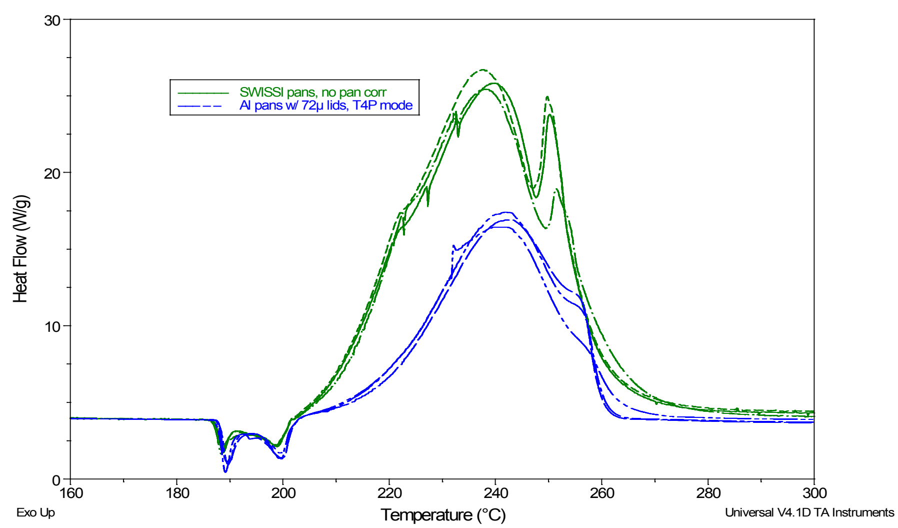

Figure 1. DSC profiles of RDX Type II Class 5 comparing data from the standard sample holder with data from the SWISSI sealed sample holders.

IHD was having issues with sample holder rupture for Set 3 and chose to make measurements with the SWISSI sample holders that are designed to remain sealed up to 300 atmospheres pressure. Figure 1 shows the DSC profiles for the RDX taken with the SWISSI sample holders (green lines) compared to the standard pinhole Al sample holders (blue lines). Three differences are apparent for the data produced using the SWISSI sample holder compared to the data produced using the pinhole sample holder: 1) the temperatures are shifted to slightly lower values for all features, 2) the enthalpies are slightly lower for the endothermic feature and at least a third higher for the exothermic feature, and 3) there is resolution of a higher temperature shoulder at ~ 250 °C. These features can readily be explained by the use of the SWISSI sample holder. The SWISSI has a larger mass than the Al sample holder so the more energy is needed to heat the SWISSI sample holder, so therefore there is a response lag manifested through a temperature shift. The sealed holder reduces the amount of enthalpy lost to the evolution decomposition gases, so therefore the heat flow out of the sample is higher and the high temperature shoulder is better resolved.

4.2 Comparison of average values for RDX Type II Class 5 average values and Set 1

In the IDCA analysis reports for $KClO_3$/icing sugar (100)[24], $KClO_3$/icing sugar (AR)[25], $KClO_3$/dodecane[26], $KClO_4$/dodecane[27], $KClO_4$/carbon[28], $KClO_4$/Al[29], $NaClO_3$/icing sugar[30], and PETN[22], the RDX data used for standard comparison has been from RDX Type II Class 5 Set 1. The Average of Sets calculated in this report will be used for the standard values in future reports. However a comparison of the two sets of values shown in Table 9 is useful.

Impact sensitivity. The values for Average of Sets for LLNL and LANL show a more sensitive material compared to the corresponding values for Set 1. It needs to be emphasized that the values for Average of Sets are derived from impact data produced using only 180-grit garnet sandpaper. IDCA has documented many cases where the sandpaper type makes a difference when assessing impact sensitivity[31]. The values of the Average of Sets and Set 1 for the IHD were produced with 180-grit garnet sandpaper and are the same.

Friction sensitivity. The TIL values for the Average of Sets for LLNL and LANL determined by BAM friction show a material slightly more sensitive than for the corresponding values of Set 1. This is also seen in the F_{50} values. However, statistically, these values are not distinguishable. The F_{50} values for Average of Sets for LLNL range 21.0 to 25.8 kg, and for Set 1 range from 24.6 to 26.2 kg; for corresponding values for LANL Set 1 range from 16.6 to 21.0 kg and 18.6 to 23.0 kg. IHD did not perform Bruceton analysis on the BAM friction data for the Set 1. However, the Average of Set and Set 1 TIL values are identical.

IHD only determined ABL Friction values for Set 1-3. The values for the Average of Sets show a slightly more stable material than the values for Set 1.

Spark sensitivity. LLNL used a custom built ESD system for some Set 1 and Set 2 measurements. This system has a 510-Ω resister in the circuit mimicking the human body. Data for Sets 3 and 4 were taken with a new ABL system recently purchased. For comparison purposes, the data for Sets 3 and 4 are used in the calculation of values for the Average of Sets. The RDX Set 1 values show no spark sensitivity. The Average of Sets value indicates low sensitivity, but is different because of the experimental configuration. For LANL, the Average of Sets and Set 1 values are essentially the same. For IHD, the Average of Sets value shows a more sensitive material than for the Set 1 values.

Thermal sensitivity. Forty-six independent DSC measurements have been performed on RDX Type II Class 5 from the three different laboratories. The results are essentially the same.

Effect of density (pressing or not pressing). LLNL also tested the RDX Type II Class 5 in pellet (pressed) form for both the Set 1 and Set 2. In both cases, 120-grit Si/C sandpaper was used—Set 1, DH_{50} = 28.8 cm; Set 2, DH_{50} = 34.0 cm. It is not clear why the values between Set 1 and Set 2 are different. It could be a difference in densities of the pellets because this is not measured. However, both values reflect more stability than the corresponding values obtained from testing the powder form.

Neyer method for 50% probability of reaction. LANL has performed Neyer (or D-Optimal) Method of analysis for RDX Type II Class 5 Set 1 using 150-grit garnet sandpaper for Set 1 and 180-grit sandpaper for Sets 2-4. The DH_{50} range is 23.3 to 26.1 cm. Average value shown in Table 4 is taken from Sets 2-4. The DH_{50} range is 19.7 to 22.5 cm. As in the Bruceton analysis, the dependency on sandpaper type is evident in drop hammer testing.

4.3 Comparison of RDX Type II Class 5 average values with other IDCA participant values

Other members of the IDCA, AFRL and SNL, have tested this batch of RDX. These data sets were not included here because these participants did not test the RDX multiple times. However, it is useful to compare their results with the Average of Sets values collected here. AFRL reported Set 1 results in the first RDX report[2]. The values are: DH_{50}, 15.3 ± 2.3 cm; ABL Friction, 0/20 @ 56 psig/8 fps; ESD 0/20 @ 0.043 J; DSC, T_{min} En_1 189.2 ± 0.6 °C, T_{min} En_2 199.1 ± 0.1 °C, ΔH En_{1+2} 144 ± 3 J/g, T_{max} Ex_1 242.3 ± 1.5 °C, ΔH Ex_1 2216 ± 29 J/g. SNL reported Set 2 results in the second RDX report[17]. The values are: DH_{50}, 23.3 ± 1.6 cm; BAM Friction, 0/20 @ 16.8 kg; ESD 0/20 @ 0.15 J; (no DSC).

4.4 Comparison of RDX Type II Class 5 with PETN Standard

Table 9 compares the RDX Type II Class 5 Average of Sets and Set 1 values with those of PETN, also obtained in this Proficiency Test[22]. For impact and friction sensitivity, all the participants found the PETN more sensitive. The results for spark sensitivity depend upon the participant. LLNL found the PETN to be more sensitive for results obtained by the custom built system and the new ABL system. LANL found the RDX to be about the same sensitivity as the PETN, while IHD found the PETN to be much less sensitive. All found the RDX to be less thermally sensitive than PETN.

5 CONCLUSIONS

Conclusions from the data for RDX Type II Class 5 of all the sets (Average of Sets, Sets 1-4 when applicable):

1. The impact sensitivity is measured to be
    a. about the same by LLNL and LANL when the samples are in the powder form
    b. about 10% lower by IHD than LLNL and LANL
2. The impact sensitivity appears less when samples are pelletized
3. All participants reported almost identical results for the DSC of RDX
4. The friction sensitivity as measured by BAM is assessed less by LLNL
5. The ESD sensitivity varies among participants
    a. LLNL, LANL and IHD measured comparable sensitivities when using the ABL system
    b. LLNL found the RDX to be insensitive when using the custom built system

Conclusions from comparison of the Average of Sets values with Set 1 values for a specific participant:

1. Impact sensitivity is slightly more for LLNL and LANL

2. For BAM friction, the Average of Sets values indicates a material more sensitive than the Set 1 values
3. For ABL friction (for IHD only), Set 1 appears more sensitive than the Average of Sets
4. For ESD, LANL finds the Average of Sets value to be the same as Set 1 value, IHD finds the Average of Sets value to indicate a material more sensitive than the Set 1 value.
5. For DSC, all participants find Average of Sets values to be essentially the same as Set 1 values.

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APPENDICES

Appendix 1. Impact data for RDX Type II Class 5

Table A-1a. Impact data for RDX Type II Class 5 by Bruceton Analysis Method

Lab[1]	Set	Striker, kg	Test Date	T, °C	RH, %[2]	DH_{50}, cm[3]	s, cm[4]	s, log unit[4]
LLNL (120^{p})[5]	1	2.5	11/19/09	24	18	28.8	2.8	0.042
LLNL (120)	1	2.5	02/08/10	23	22	24.2	0.8	0.015
LLNL (120)	1	2.5	02/16/10	23	23	24.0	1.9	0.035
LLNL (120^{p})[5]	2	2.5	9/8/10	23.9	32	34.0	4.63	0.059
LLNL (180)	2	2.5	9/9/10	23.9	30	22.9	2.22	0.042
LLNL (180)	2	2.5	9/13/10	22.8	23	20.7	4.56	0.095
LLNL (120)	3	2.5	4/24/11	23.9	18	24.8	3.09	0.054
LLNL (180)	3	2.5	5/4/11	23.9	18	22.8	4.65	0.088
LLNL (180)	3	2.5	5/4/11	23.9	18	21.4	2.02	0.041
LLNL (180)	4	2.5	5/25/11	23.9	20	22.1	2.29	0.045
LLNL (180)	4	2.5	5/25/11	23.3	21	23.3	1.88	0.035
LLNL (180)	4	2.5	5/27/11	23.3	22	24.8	3.90	0.068
LLNL (180)	4	1.0	11/28/11	23.9	21	26.0	9.10	0.149
LLNL (180)	4	1.0	11/28/11	23.9	21	26.5	2.14	0.035
LANL (150)	1	0.8	11/23/09	21	17	26.5	1.2	0.019
LANL (150)	1	0.8	11/23/09	22	16	25.5	1.1	0.019
LANL (150)	1	0.8	11/23/09	22	16	24.2	1.5	0.027
LANL (180)	2	0.8	12/06/10	22.3	< 16	22.0	1.52	0.030
LANL (180)	2	0.8	12/09/10	21.7	< 16	20.3	2.30	0.049
LANL (180)	2	0.8	12/10/10	21.7	< 16	20.0	2.26	0.049
LANL (180)	3	0.8	4/6/11	22.9	< 10	23.3	1.45	0.027
LANL (180)	3	0.8	4/12/11	21.8	< 10	23.1	2.56	0.048
LANL (180)	3	0.8	4/12/11	21.7	< 10	23.1	1.60	0.030
LANL (180)	4	0.8	5/10/11	23.1	< 10	19.6	2.81	0.062
LANL (180)	4	0.8	5/11/11	20.4	< 10	17.7	4.82	0.117
LANL (180)	4	0.8	5/12/11	21.2	< 10	19.2	6.44	0.143
IHD (180)	1	2.5	11/24/09	26	38	22	8.3	0.16
IHD (180)	1	2.5	01/11/10	26	38	19	8.1	0.18
IHD (180)	1	2.5	01/20/10	26	40	18	10.9	0.25
IHD (180)	1	2.5	01/20/10	26	40	18	4.6	0.11
IHD (180)	2	2.5	3/8/11	28	40	17	4.76	0.12
IHD (180)	2	2.5	3/9/11	24	43	21	1.94	0.04
IHD (180)	2	2.5	3/8/11	29	43	15	3.13	0.09
IHD (180)	3	2.5	1/4/12	24	42	24	3.33	0.06
IHD (180)	3	2.5	2/15/12	26	43	21	2.91	0.07
IHD (180)	3	2.5	4/11/12	27	41	22	2.54	0.05

1. Value in parenthesis is grit size of sandpaper (180 is 180 garnet dry 150 is garnet dry and 120 is 120 Si/Carbide wet/dry); 2 relative humidity; 3. DH_{50}, in cm, from a modified Bruceton method, height for 50% probability of reaction (DH_{50}); 4. Standard deviation; 5. p = pressed into pellet

Table A-1b. Impact data for RDX Type II Class 5 by Neyer (D-Optimal) Analysis Method

Lab[1,5]	Set	Test Date	T, °C	RH, %[2]	DH_{50}, cm[3]	s, cm[4]	s, log unit[4]
LANL (150)	1	12/24/09	20	17	24.0	3.3	0.06
LANL (150)	1	12/24/09	20	17	24.4	3.4	0.06

Lab[1,5]	Set	Test Date	T, °C	RH, %[2]	DH_{50}, cm[3]	s, cm[4]	s, log unit[4]
LANL (150)	1	12/24/09	20	17	23.7	2.7	0.05
LANL (150)	1	4/8/10	24.2	<10	26.7	5.6	0.09
LANL (180)	2	4/8/10	24.2	<10	20.4	3.3	0.07
LANL (180)	2	12/06/10	21.8	< 10	23.2	2.5	0.047
LANL (180)	2	12/09/10	21.8	< 10	21.2	2.3	0.047
LANL (180)	2	12/10/10	21.7	< 10	20.1	1.3	0.028
LANL (180)	3	4/6/11	22.5	< 10	20.6	3.7	0.079
LANL (180)	3	4/12/11	22.1	< 10	23.3	1.0	0.019
LANL (180)	3	4/12/11	21.8	< 10	21.3	1.5	0.031
LANL (180)	4	5/10/11	22.9	< 10	18.7	5.6	0.134
LANL (180)	4	5/11/11	20.4	< 10	21.9	2.8	0.056
LANL (180)	4	5/11/11	20.2	< 10	20.1	5.8	0.129

1. Value in parenthesis is grit size of sandpaper (180 is 180 garnet dry 150 is 150 is garnet dry); 2 relative humidity; 3. DH_{50}, in cm, from a Neyer D-Optimal method, height for 50% probability of reaction; 4. Standard deviation; 5. 0.8 kg Striker weight.

Appendix 2. Friction Data for RDX Type II Class 5.

Table A-2a. BAM Friction Data for RDX Type II Class 5

Lab	Set	Test Date	T, °C	RH, %[1]	TIL, kg[2]	TIL, kg[3]	F_{50}, kg[4]	s, kg[5]	s, log unit[5]
LLNL	1	11/23/09	22.8	18	0/10 @ 19.2	1/10 @ 21.6	25.4	3.2	0.054
LLNL	1	02/09/10	22.8	23	0/10 @ 21.6	1/10 @ 24.0	24.6	2.8	0.050
LLNL	1	02/16/10	22.8	30	0/10 @ 16.8	1/10 @ 19.2	26.1	4.2	0.070
LLNL	2	9/08/10	23.9	26	0/10 @ 16.0	1/10 @ 16.8	23.1	1.86	0.035
LLNL	2	9/09/10	23.9	31	0/10 @ 16.8	1/10 @ 18.0	25.4	3.17	0.054
LLNL	2	9/09/10	23.9	31	0/10 @ 16.8	1/10 @ 19.2	26.0	3.00	0.050
LLNL	3	4/28/11	23.9	20	NA[6]	NA[6]	19.8	3.58	0.078
LLNL	3	5/3/11	23.9	15	NA[6]	NA[6]	23.2	5.27	0.098
LLNL	3	5/4/11	23.9	13	NA[6]	NA[6]	20.3	1.97	0.042
LLNL	4	5/25/11	23.9	23	0/10 @ 16.0	1/10 @16.8	20.6	2.76	0.058
LLNL	4	5/26/11	23.9	20	0/10 @ 16.8	1/10 @ 17.4	25.0	1.56	0.027
LLNL	4	5/27/11	21.7	24	0/10 @ 16.0	1/10 @ 16.8	21.1	1.31	0.042
LANL	1	11/23/09	22.0	16.0	NA[6]	NA[6]	20.8	3.4	0.07
LANL	1	11/24/09	20.0	17.0	NA[6]	NA[6]	23.0	2.1	0.04
LANL	1	11/24/09	21.0	17.0	NA[6]	NA[6]	18.7	5.2	0.12
LANL	1	01/11/10	19.1	< 10	0/10 @ 19.2	1/4 @ 21.6	NA[7]	NA[7]	NA[7]
LANL	2	12/06/10	22.1	< 10	0/10 @ 9.6	1/8 @ 12.0	NA[7]	NA[7]	NA[7]
LANL	2	12/08/10	21.1	< 10	0/10 @ 12.0	1/3 @ 14.4	NA[7]	NA[7]	NA[7]
LANL	2	12/08/10	22.1	< 10	0/10 @ 9.6	1/5 @ 12.0	NA[7]	NA[7]	NA[7]
LANL	2	12/0610	22.2	< 10	NA[6]	NA[6]	15.1	3.6	0.106
LANL	2	12/08/10	20.8	< 10	NA[6]	NA[6]	16.7	2.3	0.060
LANL	2	12/08/10	20.8	< 10	NA[6]	NA[6]	17.1	1.8	0.046
LANL	3	4/11/11	22.0	< 10	NA[6]	NA[6]	14.9	1.73	0.051
LANL	3	4/11/11	21.8	< 10	NA[6]	NA[6]	16.7	2.96	0.078
LANL	3	4/11/11	21.8	< 10	NA[6]	NA[6]	15.1	1.73	0.086
LANL	3	4/11/11	21.8	< 10	0/10 @ 12.2	1/5 @ 14.7	NA[7]	NA[7]	NA[7]
LANL	3	4/11/11	21.8	< 10	0/10 @ 12.2	1/1 @ 14.7	NA[7]	NA[7]	NA[7]
LANL	3	4/11/11	21.9	< 10	0/10 @ 9.8	1/9 @ 12.2	NA[7]	NA[7]	NA[7]
LANL	4	5/10/11	21.8	< 10	NA[6]	NA[6]	19.4	3.7	0.084
LANL	4	5/10/11	23.4	< 10	NA[6]	NA[6]	20.4	1.3	0.028
LANL	4	5/10/11	22.6	< 10	NA[6]	NA[6]	21.4	1.5	0.030
LANL	4	5/11/11	23.4	< 10	0/10 @ 12.2	1/10 @ 14.7	NA[7]	NA[7]	NA[7]
LANL	4	5/11/11	23.4	< 10	0/10 @ 14.7	1/4 @ 17.1	NA[7]	NA[7]	NA[7]
LANL	4	5/11/11	23.5	< 10	0/10 @ 14.7	1/6 @ 17.1	NA[7]	NA[7]	NA[7]
IHD	1	11/25/09	26	37	0/10 @ 14.7	1/3 @ 16.3	NA[7]	NA[7]	NA[7]
IHD	1	01/25/10	27	49	0/10 @ 14.7	1/6 @ 16.3	NA[7]	NA[7]	NA[7]
IHD	1	01/25/10	27	46	0/10 @ 16.3	1/2 @ 18.4	NA[7]	NA[7]	NA[7]
IHD	1	01/25/10	27	48	0/10 @ 14.7	1/4 @ 16.3	NA[7]	NA[7]	NA[7]
IHD	2	3/31/11	23	40	0/10 @ 11.0	1/4 @ 12.2	NA[7]	NA[7]	NA[7]
IHD	2	2/23/11	26	40	0/10 @ 12.2	1/5 @ 14.7	NA[7]	NA[7]	NA[7]
IHD	2	4/22/11	22	40	0/10 @ 12.2	1/5 @ 14.7	NA[7]	NA[7]	NA[7]
IHD[8]	2	4/11/11	NA[9]	NA[9]	NA[6]	NA[6]	31.6	7.0	0.098
IHD[8]	2	4/11/11	NA[9]	NA[9]	NA[6]	NA[6]	24.9	12.0	0.228
IHD[8]	2	4/11/11	NA[9]	NA[9]	NA[6]	NA[6]	26.9	23.7	0.600
IHD	3	1/3/12	26	42	0/10 @ 12.2	1/3 @14.7	NA[7]	NA[7]	NA[7]
IHD	3	2/16/12	27	43	0/10 @ 11.0	1/1 @ 12.2	NA[7]	NA[7]	NA[7]
IHD	3	4/11/12	28	40	0/10 @ 11.0	1/3 @ 12.2	NA[7]	NA[7]	NA[7]

Lab	Set	Test Date	T, °C	RH, %[1]	TIL, kg[2]	TIL, kg[3]	F_{50}, kg[4]	s, kg[5]	s, log unit[5]
IHD	3	6/8/12	20	41	NA[6]	NA[6]	19	2.3	0.053
IHD	3	6/8/12	20	42	NA[6]	NA[6]	20	2.9	0.063
IHD	3	6/8/12	20	42	NA[6]	NA[6]	19	3.0	0.069

1. Relative humidity; 2. Threshold Initiation Level (TIL) is the load (kg) at which zero reaction out of twenty or fewer trials with at least one reaction out of twenty or fewer trials at the next higher load level; 3. Next level where positive initiation is detected; 4. F_{50}, in kg, is by a modified Bruceton method, weight for 50% probability of reaction; 5. Standard deviation; 6. Not applicable, separate measurement performed for TIL; 7. Not applicable, separate measurements performed for modified Bruceton analysis. 8. Modified Neyer analysis; 9. Not measured. LLNL uses log-spacing and LANL uses liner spacing for the Bruceton up and down method experimentation and data analysis.

Table A-2b ABL Friction analysis of RDX Type II Class 5

Lab	Set	Test Date	T, °C	RH, %[1]	TIL, psig/fps[2,3]	TIL, psig/fps[2,4]	F_{50}, psig/fps[2,5]	s, psig/fps[6]	s, log unit[6]
IHD	1	11/24/09	26	36	0/20 @ 75/8	1/6 @ 100/8	NA[7]	NA[7]	NA[7]
IHD	1	01/21/10	27	44	0/20 @ 30/8	1/1 @ 40/8	183/8	175/8	0.37
IHD	1	01/21/10	26	43	0/20 @ 75/8	1/5 @ 100/8	NA[7]	NA[7]	NA[7]
IHD	1	01/21/10	27	41	0/20 @ 40/8	1/2 @ 55/8	NA[7]	NA[7]	NA[7]
IHD	1	01/25/10	27	43	NA[8]	NA[8]	118/8	30/8	0.11
IHD	1	01/25/10	27	46	NA[8]	NA[8]	163/8	46/8	0.12
IHD	2	3/31/11	23	40	0/20 @ 75/8	1/1 @ 100/8	NA[7]	NA[7]	NA[7]
IHD	2	3/16/11	25	44	0/20 @ 100/8	1/9 @ 135/8	NA[7]	NA[7]	NA[7]
IHD	2	3/31/11	23	40	0/20 @ 100/8	1/6 @ 135/8	NA[7]	NA[7]	NA[7]
IHD	2	3/31/11	23	40	NA[8]	NA[8]	224/8	57.3/8	0.11
IHD	2	3/17/11	25	42	NA[8]	NA[8]	196/8	59.4/8	0.13
IHD	2	3/31/11	23	41	NA[8]	NA[8]	200/8	60.8/8	0.13
IHD	3	1/3/12	26	42	0/20 @ 75/8	1/9 @ 100/8	NA[7]	NA[7]	NA[7]
IHD	3	5/18/12	19	41	0/20 @ 100/8	1/3 @ 135/8	NA[7]	NA[7]	NA[7]
IHD	3	6/29/12	23	43	0/20 @ 100/8	1/4 @ 135/8	NA[7]	NA[7]	NA[7]
IHD	3	6/6/12	20	46	NA[8]	NA[8]	178/8	37.2/8	0.09
IHD	3	6/6/12	20	40	NA[8]	NA[8]	174/8	61.3/8	0.15
IHD	3	6/6/12	20	41	NA[8]	NA[8]	181/8	42.0/8	0.10
IHD	4	11/15/12	24	40	0/20 @ 75/8	1/7 @ 100/8	NA	NA	NA
IHD	4	1/24/13	22	44	0/20 @ 75/8	1/5 @ 100/8	NA	NA	NA
IHD	4	2/27/13	26	41	0/20 @ 75/8	1/7 @ 100/8	NA	NA	NA
IHD	4	3/8/13	24	40	NA	NA	144/8	33.5/8	0.10
IHD	4	3/8/13	24	40	NA	NA	174/8	28.2/8	0.07
IHD	4	3/8/13	24	40	NA	NA	162/8	57.1/8	0.15

1. Relative humidity; 2. psig/fps = pressure in psig at test velocity in feet per sec; 3. Threshold Initiation Level (TIL) is the load (psig) at test velocity (fps) at which zero reaction out of twenty or fewer trials with at least one reaction out of twenty or fewer trials at the next higher load level; 4. Next level where positive initiation is detected; 5. F_{50}, in psig/fps, is by a modified Bruceton method, force for 50% probability of reaction; 6. Standard deviation; 7. Not applicable, separate measurements done for modified Bruceton analysis; 8. Not applicable, separate measurements performed for TIL analysis.

Appendix 3. Electrostatic discharge data for RDX Type II Class 5.

Table A-3a. ESD Testing results for RDX Type II Class 5

Lab	Set	Ω	Test Date	T, °C	RH, %[1]	TIL, Joule[2]	TIL+, Joule[3]
LLNL	1	510[4]	11/18/09	22.8	18	0/10 @ 1.0	0/10 @ 1.0[4]
LLNL	1	510[4]	02/08/10	22.8	23	0/10 @ 1.0	0/10 @ 1.0[4]
LLNL	1	510[4]	02/16/10	22.8	30	0/10 @ 1.0	0/10 @ 1.0[4]
LLNL	2	510[4]	9/08/10	23.9	26	0/10 @ 1.0	0/10 @ 1.0
LLNL	2	510[4]	9/08/10	23.9	32	0/10 @ 1.0	0/10 @ 1.0
LLNL	2	510[4]	9/10/10	23.9	29	0/10 @ 1.0	0/10 @ 1.0
LLNL	3	0[5]	4/20/11	23.9	21	0/10 @ 0.038	1/2 @ 0.063
LLNL	3	0[5]	4/26/11	23.9	16	0/10 @ 0.038	1/3 @ 0.063
LLNL	3	0[5]	4/26/11	23.9	16	0/10 @ 0.038	1/3 @ 0.063
LLNL	4	0[5]	4/26/11	23.3	22	0/10 @ 0.038	1/3 @ 0.063
LLNL	4	0[5]	4/26/11	24.4	20	0/10 @ 0.038	1/2 @ 0.063
LLNL	4	0[5]	4/26/11	23.3	21	0/10 @ 0.038	1/6 @ 0.063
LANL	1	0[5]	11/24/09	20	17	0/20 @ 0.025	2/11 @ 0.0625
LANL	1	0[5]	11/24/09	19	17	0/20 @ 0.025	2/7 @ 0.0625
LANL	1	0[5]	11/24/09	19	17	0/20 @ 0.025	2/7 @ 0.0625
LANL	2	0[5]	12/06/10	22.2	< 10	0/20 @ 0.025	1/17 @ 0.0625
LANL	2	0[5]	12/08/10	21.0	< 10	0/20 @ 0.0625	1/1 @ 0.125
LANL	2	0[5]	12/08/10	20.9	< 10	0/20 @ 0.025	1/13 @ 0.0625
LANL	3	0[5]	4/11/11	22.3	< 10	0/20 @ 0.025	1/9 @ 0.0625
LANL	3	0[5]	4/11/11	21.9	< 10	0/20 @ 0.025	1/3 @ 0.0625
LANL	3	0[5]	4/11/11	22.0	< 10	0/20 @ 0.025	2/16 @ 0.0625
LANL	4	0[5]	5/5/11	23.4	< 10	0/20 @ 0.025	1/12 @ 0.0625
LANL	4	0[5]	5/5/11	23.6	< 10	0/20 @ 0.025	1/10 @ 0.0625
LANL	4	0[5]	5/5/11	22.9	< 10	0/20 @ 0.025	1/7 @ 0.0625
IHD	1	0[5]	11/24/09	26	36	0/20 @ 0.095	1/7 @ 0.165
IHD	1	0[5]	01/15/10	27	40	0/20 @ 0.095	1/7 @ 0.165
IHD	1	0[5]	01/15/10	27	40	0/20 @ 0.095	1/14 @ 0.165
IHD	1	0[5]	01/19/10	27	40	0/20 @ 0.095	1/12 @ 0.165
IHD	2	0[5]	3/10/11	24	42	0/20 @ 0.037	1/4 @ 0.095
IHD	2	0[5]	3/10/11	24	42	0/20 @ 0.037	1/3 @ 0.095
IHD	2	0[5]	3/16/11	24	42	0/20 @ 0.037	1/16 @ 0.095
IHD	3	0[5]	11/20/11	28	42	0/20 @ 0.037	1/7 @ 0.095
IHD	3	0[5]	1/4/12	23	40	0/20 @ 0.095	1/8 @ 0.165
IHD	3	0[5]	2/16/12	26	42	0/20 @ 0.095	1/8 @ 0.165

1. Relative humidity; 2. Threshold Initiation Level (TIL) is the load (joules) at which zero reaction out of twenty or fewer trials with at least one reaction out of twenty or fewer trials at the next higher load level; 3. Next level where positive initiation is detected; 4. LLNL used a custom built ESD with a 510-Ω resistor in the discharge unit to mimic the human body; 5. ABL ESD with 0-Ω resistance.

Appendix 4. DSC Data for RDX Type II Class 5

Table A-4a. DSC data for RDX Type II Class 5

Lab	Set	Sample Holder	Test Date	Endothermic, onset/minimum, °C (ΔH, J/g)	Exothermic, onset[1]/maximum, °C (ΔH, J/g)
LLNL	1	Pinhole[2]	12/01/09	187.5/189.0, 199.2 (143)	203/241.1 (2281)
LLNL	1	Pinhole[2]	02/04/10	187.8/189.1, 199.3 (139)	203/240.7 (2299)
LLNL	1	Pinhole[2]	02/04/10	187.8/189.1, 198.8 (136)	203/241.5 (2316)
LLNL	1	Sealed[3]	12/01/09	187.4/188.9, 199.2 (125)	205/233.5 (3024)
LLNL	1	Sealed[3]	02/04/10	187.7/188.9, 198.8 (144)	205/235.6 (2880)
LLNL	1	Sealed[3]	02/04/10	187.6/189.1, 198.8 (125)	203/233.7 (2998)
LLNL	2	Pinhole[2]	8/27/10	187.3/188.3, 199+[4] (126)	213.13/240.1 (2432)
LLNL	2	Pinhole[2]	8/27/10	187.5/188.6, ~200[4] (129)	215.61/240.6 (2419)
LLNL	2	Pinhole[2]	8/27/10	187.4/188.4, 199+[4] (135)	217.91/238.7 (2399)
LLNL	2	Sealed[3]	8/27/10	187.3/188.3, 199+[4] (126)	215.63/238.0 (3517)
LLNL	2	Sealed[3]	8/27/10	187.3/188.3, 199+[4] (132)	214.63/231.2 (3478)
LLNL	2	Sealed[3]	8/27/10	187.4/188.3, 199+[4] (114)	215.23/230.6 (3805)
LLNL	3	Pinhole[2]	4/1/11	187.8/188.9, 199.2 (140)	217.1/242.4 (2353)
LLNL	3	Pinhole[2]	4/1/11	187.8/189.2, 199.3 (154)	218.4/242.0 (1890)
LLNL	3	Pinhole[2]	4/1/11	187.8/189.1, 199.5 (181)	218.4/243.5 (1927)
LLNL	3	Sealed[3]	3/31/11	187.8/189.1, 199.4 (137)	220.0/244.0 (2003)
LLNL	3	Sealed[3]	3/3111	187.8/189.1, 199.2 (138)	217.4/237.3 (3168)
LLNL	4	Pinhole[2]	5/19/11	187.8/ 188.9, 199.2 (143)	217.7/233.0 (3385)
LLNL	4	Pinhole[2]	5/20/11	187.7/188.9, ~199+[4] (138)	216.1/238.2 (2612)
LLNL	4	Pinhole[2]	5/24/11	187.6/188.8, 198.8 (136)	217.4/232.7 (3314)
LLNL	4	Sealed[3]	5/23/11	187.7/189.0, 199.2 (141)	218.6/242.4 (2195)
LLNL	4	Sealed[3]	5/23/11	187.8/189.0, 199.2 (145)	218.7/243.5 (2186)
LLNL	4	Sealed[3]	5/23/11	187.7/188.9, 199.2 (130)	217.8/242.6 (2227)
LANL	1	Pinhole[5]	11/17/09	188.0/189.1, 199.6 (137)	218.8[3]/242.8 (2205)
LANL	1	Pinhole[5]	11/24/09	188.1/189.6, 200.7 (135)	220.9[3]/242.8 (2260)
LANL	1	Pinhole[5]	11/24/09	188.0/189.2, 199.9 (135)	224.8[3]/242.1 (2246)
LANL	2	Pinhole[5]	12/02/10	188.2/189.7, 200.5 (129)	217.03/242.4 (2091)
LANL	2	Pinhole[5]	12/09/10	188.2/189.6, 200.8 (131)	219.23/243.0 (2138)
LANL	2	Pinhole[5]	12/15/10	188.0/189.2, 199.3 (140)	218.03/242.1 (2300)
LANL	3	Pinhole[5]	4/12/11	188.6/198.8, 200.5 (137)	219.0/242.1 (2148)
LANL	3	Pinhole[5]	4/12/11	188.2/189.8, 200.1 (135)	218.8/243.0 (2097)
LANL	3	Pinhole[5]	4/12/11	188.2/189.9, 200.4 (130)	218.7/241.2 (2148)
LANL	4	Pinhole[5]	5/10/11	188.1/189.6, 200.2 (136)	215.8/242.2 (2204)
LANL	4	Pinhole[5]	5/10/11	188.3/189.5, 199.8 (115)	219.8/243.3 (2017)
LANL	4	Pinhole[5]	5/10/11	188.2/ 189.6, 200.6 (120)	220.3/244.2 (1947)
IHD	1	Pinhole[5]	11/25/09	188.0/189.2, 199.8 (120)	217.7/242.4 (1947)
IHD	1	Pinhole[5]	11/25/09	187.8/189.1, 199.4 (122)	218.0/242.3 (2034)
IHD	1	Pinhole[5]	11/25/09	188.0/189.4, 199.5 (127)	219.2/241.9 (2141)
IHD[6]	2	Pinhole[5]	9/29/09	187.7/189.2, 199.3 (107)	210.93/240.2 (1375)[6]
IHD[6]	2	Pinhole[5]	9/29/09	188.2/189.5, 199.8 (96)	201.83/244.2 (1038)[6]
IHD	3	Pinhole[5]	9/7/12	187.7/189.2, 199.7 (140)	217.0/241.7 (2312)
IHD	3	Pinhole[5]	9/7/12	188.1/189.6, 199.4 (128)	214.1/241.5 (2219)
IHD	3	Pinhole[5]	9/7/12	187.4/188.7, 198.6 (92)	213.8/239.8 (4306)
IHD	3	Sealed[7]	9/11/12	186.1/188.3, 198.5 (103)	210.5/237.9 (4310)[8]
IHD	3	Sealed[7]	9/11/12	187.6/188.9, 198.1 (100)	209.3/237.4 (4472)[9]
IHD	3	Sealed[7]	9/11/12	187.4/188.7, 198.6 (92)	213.8/239.8 (4306)[10]

1. Onset of exothermic response reported to be obscured by endothermic response as indicated by software; 2.50 um laser drilled pin-hole lid from TA Instruments; pinhole sample holder; 3. Sealed sample holder from TA Instruments; 4. Visually estimated from hard copy profile; 5. 75 um laser drilled pinhole lid from TA Instruments; 6. Pan break due to off gases; 7. Sealed, gold coated, high-pressure pans from SWISSI; 8. Additional peak on shoulder at 251.7°C; 9. Additional peak at 249.8°C; 10. Additional peak on shoulder at 250.3°C.

ABREVIATIONS, ACRONYMS AND INITIALISMS

-100	Solid separated through a 100-mesh sieve
ABL	Allegany Ballistics Laboratory
AFRL	Air Force Research Laboratory, RXQL
Al	Aluminum
AR	As received (separated through a 40-mesh sieve)
ARA	Applied Research Associates
BAM	German Bundesanstalt für Materialprüfung Friction Apparatus
C	Chemical symbol for carbon
CAS	Chemical Abstract Services registry number for chemicals
cm	centimeters
DH_{50}	The height the weight is dropped in Drop Hammer that cause the sample to react 50% of the time, calculated by the Bruceton or Neyer methods
DHS	Department of Homeland Security
DSC	Differential Scanning Calorimetry
DTA	Differential Thermal Analysis
ESD	Electrostatic Discharge
F_{50}	The weight or pressure used in friction test that cause the sample to react 50% of the time, calculated by the Bruceton or Neyer methods
fps	feet per second
H	Chemical symbol for hydrogen
H_2O	Chemical formulation for water
HME	homemade explosives or improvised explosives
HMX	Her Majesty's Explosive, cyclotetramethylene-tetranitramine
IDCA	Integrated Data Collection Analysis
IHD	Indian Head Division, Naval Surface Warfare Center
j	joules
$KClO_3$	Potassium Chlorate
$KClO_4$	Potassium Perchlorate
kg	kilograms
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
MBOM	Modified Bureau of Mines
N	Chemical symbol for nitrogen
$NaClO_3$	Sodium Chlorate
NSWC	Naval Surface Warfare Center
O	Chemical symbol for oxygen
PETN	Pentaerythritol tetranitrate
psig	pounds per square inch, gauge reading
RDX	Research Department Explosive, 1,3,5-Trinitroperhydro-1,3,5-triazine
RH	Relative humidity
RT	Room Temperature
RXQL	The Laboratory branch of the Airbase Sciences Division of the Materials & Manufacturing Directorate of AFRL
s	Standard Deviation
SEM	Scanning Electron Micrograph
Si	silicon

SNL	Sandia National Laboratories
SSST	small-scale safety and thermal
TGA	Thermogravimetric Analysis
TIL	Threshold level—level before positive event

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